

Low Quiescent Current Buck Converters for Battery-Powered Wearable Applications



Introduction

Wearable technologies are continuously advancing, offering newer and improved features in smaller form factors, thus making devices such as smartwatches, fitness trackers, and medical wearables increasingly power sensitive. These devices are primarily powered by compact energy sources, including Li-ion, Li-Po, and recently, emerging Silicon Carbon Anode (SiAnode) chemistries.

What makes power management a critical design aspect is that a large portion of wearable applications operate in an almost always-off paradigm, where the system spends most of the time in a deep sleep or standby mode, waking up only periodically in the case of measurement, data transmission, or as an event-response. In such scenarios, dynamic and switching losses of the power converter become irrelevant, and the quiescent current I_Q becomes the dominant factor governing battery life. When accumulated over extended idle periods, even a seemingly small I_Q value can lead to a significant operational lifetime reduction of the battery.

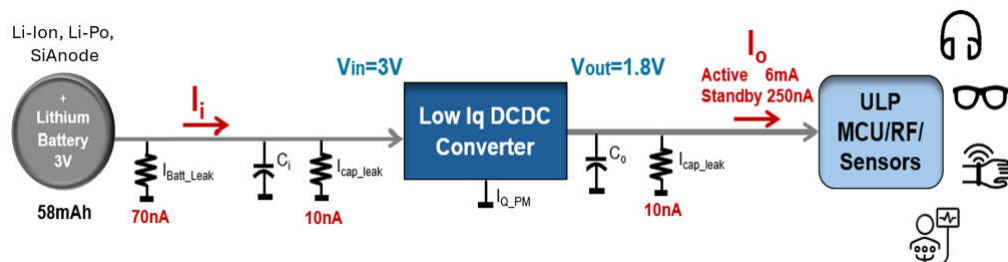


Figure 1. Low IQ Buck Converter for Battery-Powered Applications

Buck converters are widely adopted in these applications due to the inherent efficiency advantages over linear and low-dropout regulators (LDOs). However, battery-powered devices must be specifically optimized for two key requirements: minimal I_Q down to the order of a few micro-amperes or even a few hundred nano-amperes, and a small design size to fit the highly area-constrained wearable footprints. Additionally, as the industry tends towards the Silicon Carbon Anode chemistries to achieve higher energy densities, converters must be designed with the input voltage flexibility required to navigate the unique discharge profiles these batteries provide.

Texas Instruments offers a comprehensive portfolio for compact size low I_Q buck converters, engineered specifically to cater to the rigorous demands of battery-powered wearable equipment, as seen in [Figure 1](#). We are proactively evolving our product roadmap to make sure that our designs not only meet today's I_Q but are also optimized to support the next generation of battery technologies.

Three Main Specifications to Understand

When choosing the right buck converter, note the different terms in the datasheet and what those terms represent in a real-life scenario. For battery-powered wearable applications, differentiating between the following current specifications is crucial:

- **Shutdown current I_{sd} :**
 - This represents the tiny leakage current flowing when the device is disabled or operating in a shutdown mode while connected to the input supply. Generally, this is the lowest possible consumption contributor of the buck converter. All buck devices exhibit a small shutdown current when turned off and no load is present.
- **Non-switching I_Q :**
 - This is the quiescent current drawn when the buck converter is enabled but not actively switching. During this state, the internal control logic is in idle mode, therefore the current consumption is very low. An example is a pulse frequency mode (PFM) device that is turned on but under no load.
- **Switching I_Q :**
 - This current is consumed while the integrated circuit (IC) is actively switching to regulate the output voltage. Most of the internal circuitry for example, gate drivers, oscillators, control loops, are operating and yielding a higher quiescent current than in the non-switching case. A common example is a Pulse Width Modulation (PWM) buck converter that is enabled under no load, yet continuously switching.

What are the Main Challenges Customers Usually Face When Designing Battery-Powered Wearable Applications?

Whether smartwatches, fitness trackers, earbuds, medical monitors, or hearing aids, engineers are often faced with a demanding set of challenges that push the boundaries of power management. On one hand, extreme space limitation is an uncompromising constraint: wearable devices must fit within a reduced size factor, that is both comfortable and unobtrusive, leaving a limited printed circuit board (PCB) area to pack the entire power subsystem. On another hand, the critical need for an extended battery lifetime is adding to the complexity of designing wearables. Considering the wide adoption of small-capacity batteries ranging from 40mAh to 200mAh to simultaneously power the microcontroller (MCU), the wireless system (BLE/Wi-Fi®), the different integrated sensors and the display, each component in the power tree needs to be engineered to support an ultra-low quiescent current I_Q . Even microamp-level standby losses can contribute to a drastic battery lifetime shortening. The constraints must be met while ensuring high efficiency across a wide load range, since wearable systems frequently transition between active and light-load operation modes.

How to Select the Right Low IQ Buck Converter for Your Applications?

A wide range of low IQ buck converters optimized for low input voltage wearable applications are available on ti.com. [Table 1](#) lists the latest low IQ devices with current ratings, package options and recommended Bill of Material (BOM) highlighted:

Table 1. Low IQ Buck Selection Guide

	V _{in} min (V)	I _{out} max (mA)	Switching Frequency (MHz)	Efficiency	Package	Design Size (mm ²)	Typical BOM	
							L (μH)	C _{out} (μF)
TPS62840 (60nA IQ)	1.8	750	1.8	88 % (I = 10μA) 92 % (I = 100mA)	WCSP-6	<14	2.2	10, 22
					QFN-8	<17		
					HVSSOP-8	<35		
TPS62843 (275nA IQ)	1.8	600	1.5	86 % (I = 10μA) 92 % (I = 100mA)	WCSP-6	~5	1	10, 22
					SOT563-6	~5		
TPSM82843* (275nA IQ)	1.8	600	1.5	85 % (I = 10μA) 91 % (I = 100mA)	QFN-FCMOD-7	14	None	10, 22
TPS6280x (2.3μA IQ)	1.75	600	1.5	90 % (I = 1mA) 92 % (I = 400mA)	WCSP-6	5	1	4.7, 10, 22
		1000	4			3.5	0.47	
TPS62860/1 (2.3μA IQ)	1.75	600	1.5	90 % (I = 1mA) 92 % (I = 400mA, V _{out} =1.9875V)	WCSP-8	5.5	1	4.7, 10, 22
		1000	4			4	0.47	

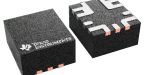
* TI has low IQ power modules such as TPSM82843 with an integrated inductor in a QFN package and TPSM82740 with 360nA IQ available in MicroSIP™ package.

All mentioned devices are designed following an RF-friendly DCS-Control™ topology.

What are the Package Options for Low IQ Low Input Voltage Buck Converters?

TI offers a variety of package and pinout options for low voltage buck converters, specifically targeting low power and size-constrained applications. The description and value proposition of each of the packages are listed in [Table 2](#).

Table 2. Package Options for Low-IQ Buck Converters

Package / Parameters	DSBGA	WCSP	SOT563-6	VSON-HR	QFN (module)
Typical Dimensions (mm × mm × mm) (L × W × H)	0.80 × 1.0 × 0.37 (6pins) 1.4 × 0.70 × 0.4 (8pins)	0.97 × 1.47 × 0.5 (6pins)	1.6 × 1.6 × 0.6	1.5 × 2 × 1 (8 pins)	2.45 × 2.7 × 1.29 (7 pins)
Value Proposition	Ultra-compact design	Small footprint, no lead frame, best for ultra-compact, low-power designs with BGA capability.	Standardized footprint	Good balance of size, thermal performance, and assembly ease.	Best overall thermal performance and mechanical robustness
					

Additional Feature Sets Provided by Low IQ Buck Converters:

MODE pin:

To maintain high efficiency over a wide load current range, our converters can automatically transition to PFM operation, also referred to as pulse-skipping mode or power save mode (PSM) as the load current decreases. In this mode, the conversion efficiency is increased by skipping switching pulses and reducing the device current consumption (quiescent current). Pulse-skipping eliminates the negative inductor current (current flowing from the output towards the input) that otherwise occurs at light loads with fixed-frequency, PWM operation. The trade-off of this mode of operation is a higher V_{out} ripple.

If a lower V_{out} ripple and cleaner noise profile is required by the application at the expense of light-load efficiency, a forced-PWM mode can be favored, where the device always operates in continuous conduction mode.

A MODE pin is available in many TI buck converters, that enables the selection between automatic transition to PFM or FPWM operation depending on the application needs. The resulting efficiency curves are shown in [Figure 2](#).

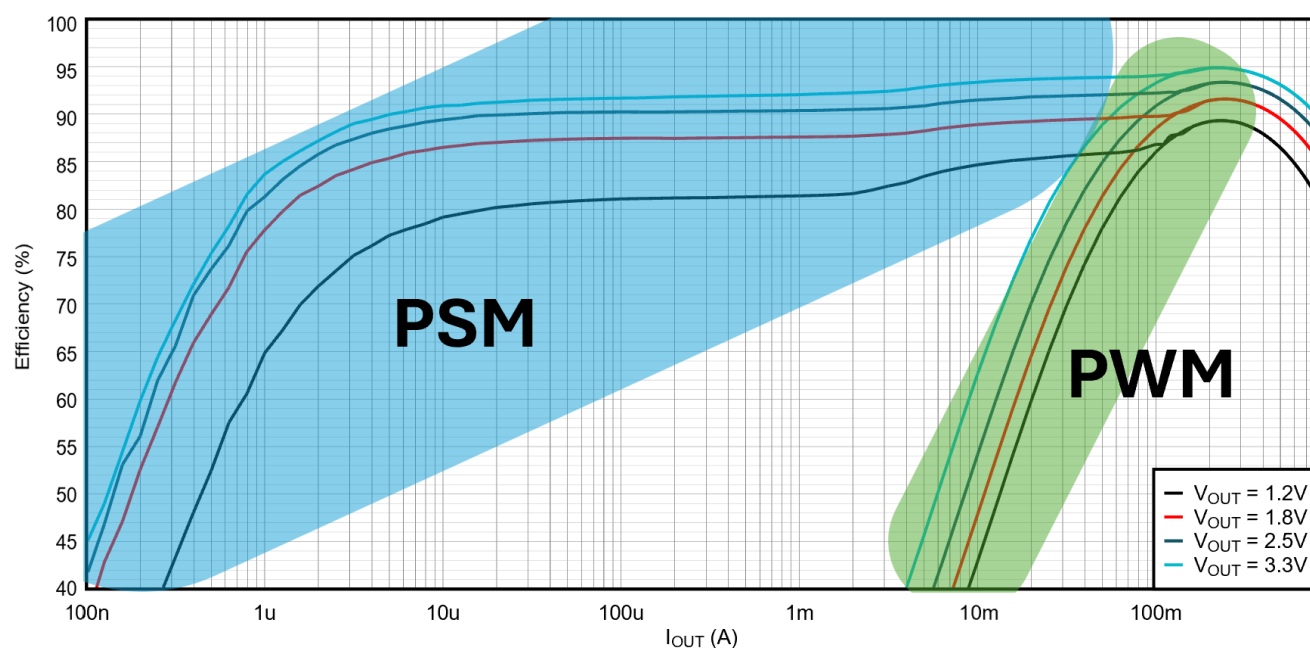


Figure 2. TPS62840 Efficiency versus Load at PSM and PWM Modes, $V_{in} = 5V$

STOP function/pin:

This STOP mode is analog to telling the buck converter *stay quiet for a moment*. A normal switching regulator is efficient, but inherently creates tiny switching noise and ripple that can disturb applications relying on distortion-free data-acquisition or RF communication procedures. When the STOP pin is set to logic high, the converter fully stops switching after the current switching cycle, and the output load is powered only from the output capacitor C_{out} for a short time. This gives the ADC, sensor or RF block a clean, quiet window to take a measurement or transmit without power-supply noise getting in the way. As soon as a logic-low level is applied to the STOP pin, the regulator immediately resumes switching operation, without any startup and/or soft-start delay.

In STOP mode, the output voltage behavior as a function of time can be estimated by:

$$V_{out}(t) = V_{out, set} - I_{out} \times \frac{t}{C_{out}}, \quad (1)$$

Where $V_{out, set}$ is the set output voltage and I_{out} is the constant output current discharging C_{out} .

The longer STOP mode is kept active, or the more current the load takes, the more the output voltage falls. A bigger output capacitor yields a slower voltage decrease. This feature is mostly important for very light-load applications where the current is in the range of 100µA to 20 mA.

Dynamic Voltage Scaling (DVS)

This is a control technique where the output voltage of the switching regulator is dynamically adjusted depending on the application system demands and the changing load conditions. DVS aims to improve energy efficiency, reduce power consumption while maintaining flexibility to adapt to rapidly changing performance requirements. During light load or idle modes, the voltage is automatically decreased in order to save power and is instantly increased during high-performance tasks as depicted in Figure 3.

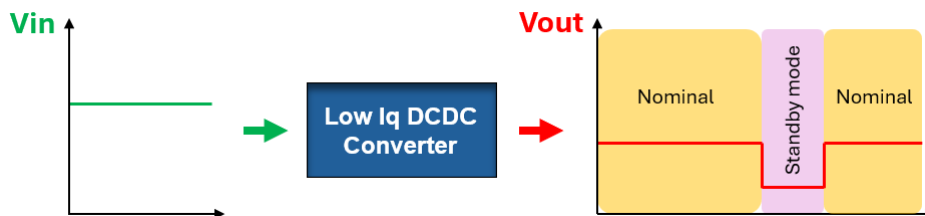


Figure 3. DCDC Buck Converter DVS Method for Power Consumption Reduction

TI implements dynamic voltage scaling through several standard approaches depending on the user's requirements:

I²C Interface:

This allows a processor to digitally change voltage presets, ramp speed, and other internal features by sending commands over a bus. This enables software-controlled, real-time adjustment of the output voltage in exact, small step sizes, for example in [TPS628600](#).

Hardware Select / VSEL Pins:

If the voltage only needs to be selected from two or up to four options using external hardware pins on the switching regulator, this can be done by changing the logic levels of these pins during operation. Examples include [TPS62740](#), [TPS62743](#), and [TPS62860](#).

TPS62860/1 offers the ability to dynamically control V_{out} via the I2C interface or a dedicated VSEL pin with different default V_{out} settings as shown in [Table 3](#) below:

Table 3. TPS62860/1 Device Comparison

Orderable Number	Output Current (A)	Default V_{out} Setting (V)	Default Operation	I2C Address	Switching Frequency (MHz)	User Interface
TPS628600YCH	0.6	0.6, 1.1	Normal (PWM, PFM) operation	0x40	1.5	EN, I2C, VSEL
TPS628601YCH	0.6	0.6, 0.7, 0.8, 1.0	Normal (PWM, PFM) operation	0x40	1.5	2xVSEL, EN, PG
TPS628603YCH	0.6	1.05, 0.65	Normal (PWM, PFM) operation	0x40	1.5	EN, I2C, VSEL
TPS628604YCH	0.6	0.85, 1.1	Normal (PWM, PFM) operation	0x40	1.5	EN, I2C, VSEL
TPS628610YCH	1	0.6, 1.1	Normal (PWM, PFM) operation	0x40	4	EN, I2C, VSEL
TPS628605YCH	0.6	1.8, 1.8	VSEL = LOW (normal (PWM, PFM) operation), VSEL = HIGH (PFWM operation)	0x41	1.5	EN, I2C, VSEL
TPS628606YCH	0.6	1.0125, 1.0125	VSEL = LOW (normal (PWM, PFM) operation), VSEL = HIGH (PFWM operation)	0x40	1.5	EN, I2C, VSEL

Learn more

1. Texas Instruments, [Light-load efficiency and low IQ](#) video
2. Texas Instruments, [Dynamic Voltage Scaling \(DVS\) Using TPS6282xA and TPS62830x](#) application brief
3. Texas Instruments, [Advantages of the STOP Function for Low-noise Data acquisition Applications](#) technical article
4. Texas Instruments, [3 Quiescent-current \(Iq\) Specifications to Understand](#) technical article
5. Texas Instruments, [Deciphering Low Iq: Using WEBENCH® to Design near 100% Duty-cycle for Ultra-low Power Applications](#) technical article
6. Texas Instruments, [IQ: What it is, what it isn't, and how to use it](#) analog applications journal
7. Texas Instruments, [Extend Battery Life with < 100 nA IQ Buck Converter Achieving < 150 \$\mu\$ V Voltage Ripple](#) application report

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